Drying of brick walls after impregnation

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Abstract

Elevated moisture due to driving rain impact on unrendered brick walls can lead to frost damage or accelerated decay of the exposed facade. Additionally, in the case of monolithic exterior walls which are often encountered in historic buildings, a high water content reduces the already low thermal resistance of the wall, thus leading to poor hygienic indoor conditions. Since the appearance of the facade should in general remain unaltered for esthetical reasons, the obvious measure to improve the moisture protection and thermal quality of brick masonry is the impregnation with water repellent agents, possibly combined with an interior insulation. In field test, the effect of siloxane impregnation on the moisture behaviour of exposed brick masonry with and without cracks was examined in comparison with untreated as well as with sheltered facades. In all cases the impregnation of exposed wall elements with elevated moisture led to a drying process which resulted in low water contents, similar to the moisture conditions of sheltered facades. The drying of the impregnated wall elements with a thickness of 24 cm takes about one year. Since monolithic brick walls of historic buildings are mostly thicker, complementary heat and moisture transport calculations were carried out for representative walls. Depending on the interior finish (e.g. insulation) of such brick walls, the drying time after impregnation ranges from 2 to 7 years. In order to avoid frost damage or a long dry-out time, an interior insulation is best applied some time after impregnation.

Key words: Brick wall, frost damage, impregnation, water repellent agents, water content, heat and moisture transport.

1. Introduction

Single layer brick walls of old buildings often lack sufficient protection against driving rain and may thus exhibit elevated moisture contents, especially on the weather side. This further reduces the mostly low thermal resistance of these walls, which may in some cases even fall below the minimum heat insulation required for hygienic reasons. Additionally, an elevated moisture content entails the danger of frost damage close to the facade. Installing an interior heat insulation, e.g. to increase thermal comfort, aggravates this danger since the drying process of the wall is slowed down and its mean temperature reduced. Prerequisite for a better thermal quality and a better protection against moisture of these walls is therefore an increased rain protection. In the case of unrendered masonry, which should retain its appearance for esthetical reasons, the only way to improve rain protection is repointing the facade and treating it with water repellent agents.

In this paper the performance of siloxane impregnation is examined in a field test and the consequences of such a treatment for the hygrothermal behaviour of single layer brick walls with and without interior insulation is analysed by experimentally verified heat and moisture transfer calculations. The drying time of representative walls after impregnation is assessed by assuming an effective long term rain protection by the water repellent treatment.

2. Experimental and numerical investigations

2.1 Combination of field tests and calculations

It has been shown in [1] that a combination of field tests and heat and moisture transport calculations can enhance the interpretation and transferability of experimental results concerning the hygrothermal behaviour of building components. If the measured and calculated results for a certain construction element correspond well, it can be assumed that the dominant factors for the hygrothermal behaviour of the considered construction are correctly implemented in the calculation model. This means that further conclusions can be drawn by a numerical study without additional costly and time consuming field tests.

2.2 Experimental set-up

In a test hall which is conditioned during wintertime of 20 °C and 50 % R.H., masonry elements with a surface of 60x60 cm^2 and a thickness of 24 cm have been exposed with one side facing to the wet and to the east, respectively [2]. The western facade of the hall faces a plain without any obstructions. The amount of driving rain hitting the facade varies between about 400 to 500 l/m^2 a year. The eastern facade is sheltered by a overhanging roof, so that hardly any rain water hits it.

The masonry in the wall elements is made of solid brick (format: 24x11.5x5 cm^3) and lime-cement mortar. The mortar gaps have a thickness of about 15 mm. At some elements, artificial cracks were introduced with a thin wire while the mortar was still soft, which led to cracks of up to 1 mm in thickness between the mortar and the brick. After exposing the wall elements to the natural climate in Holzkirchen (Bavaria), the water content was monitored by weighing the elements about once a month. Due to unusually dry weather at the beginning of the observation period, the elements facing west were sprayed by a lawn sprinkler in the end of May 1993 in order to obtain a representative water content. Five days later, half of the wall elements were treated with siloxane in organic solvent while the other half of the elements remained untreated. The impregnation was applied twice with the aid of a paint brush by wetting the surface thoroughly. The total amount of solution taken up by the masonry was about 0.3 kg/m^2. After the treatment, the moisture behaviour of the wall elements was registered by discontinuous weighing for a period of more than two years. Towards the end of the observation period, the rain protection of one element was blemished by drilling holes (diameter 3 cm) in the facade and filling them with untreated lime-cement mortar, thereby producing an unimpregnated area of less than 2 % of the facade element.

2.3 Heat and moisture transfer calculations

The calculations are done with the PC-program WUFI, a one-dimensional version of the calculation model described in [3]. Although this model has been validated by comparison with experimental results several times, a verification of the calculations for this case is necessary because the material parameters of the masonry have to be approximated from standard material properties as listed in table 1. The resulting liquid diffusivities for water absorption and liquid redistribution, res. drying, are shown in Fig. 1. The retention curve is approximated from the sorption moisture at 80 % R.H. and the capillary saturation according to [3]. As boundary conditions for the comparison, the

Table 1: Hygrothermal parameters of brick masonry and the interior insulation materials.

material	brick masonry	expanded polystyrene	mineral wool	insulating plaster
density [kg/m^3]	1900	15	60	310
thermal conductivity [W/mK]	0.6	0.04	0.04	0.07
moisture related increase of λ [%/M.-%]	15	--	--	1
vapour diffusion resistance factor [-]	10	30	1.3	8
sorption moisture at 80 % R.H. [Vol.-%]	1.8	--	--	1.3
capillary saturation [Vol.-%]	19	--	--	20

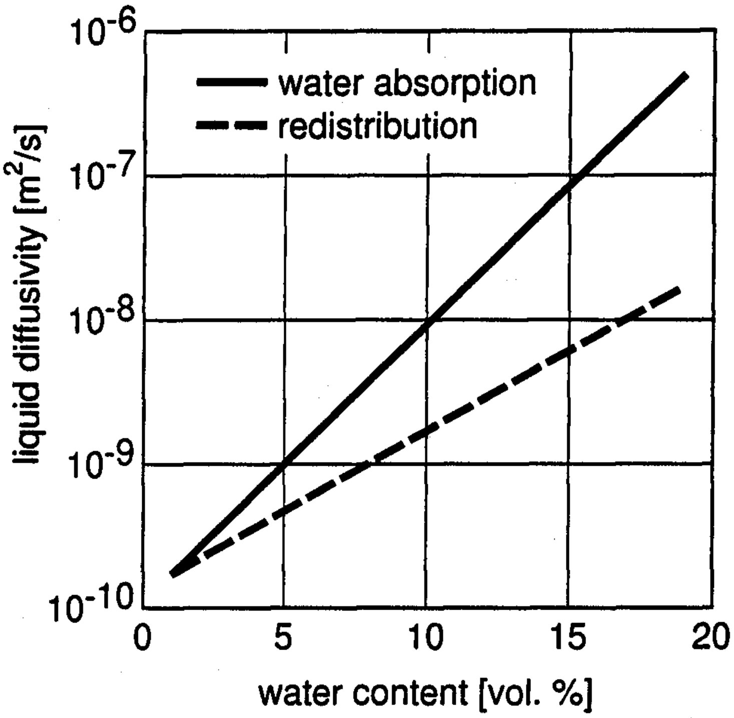

Fig. 1: Liquid diffusivity of the brick masonry for water absorption during rain periods and the redistribution respectively drying process.

measured meteorological data, i.e. temperature, relative humidity, driving rain and solar radiation of the test period, are used in form of hourly mean values. The initial moisture content assumed for this calculation is the water content after the spray-wetting of the wall elements assuming a uniform distribution. The effect of the water repellent impregnation is simulated by a non water-absorbing surface and an additional surface diffusion resistance of 0.2 m which was measured by a wet-cup test.

The thickness of the tested wall elements is not representative for single layer brick walls found in old buildings, which are mostly at least 40 cm thick. The same holds for the precipitation load in Holzkirchen which is classified in driving rain group III according to [4]. Unrendered brick walls cannot bear such a high load and are therefore uncommon in areas classified in group III. Therefore, the driving rain load in the outdoor boundary conditions taken from an average year in Holzkirchen has been reduced to one third of the measured amount. The interior temperatures and relative humidities are approximated by sine waves with mean value of 22 °C and 50 % relative humidity and amplitudes of 2 K and 10 % R.H., respectively. The maximum values are reached in July.

In contrast to [5], where the moisture distribution in an exposed wall was derived from the measured distribution in a rendered brick wall, the conditions in untreated walls without insulation and with 6 cm of interior insulation using different insulation materials (material parameters are given in table 1) is determined by calculating over several years applying the same meteorological data until no changes from one year to another are observed anymore. From the thus obtained moisture distribution, the drying behaviour of the walls after impregnation is calculated assuming a perfect rain protection, i.e. without water absorption of the exposed surface.

3. Results

3.1 Performance of siloxane impregnation in the field test

The course of the change in water content of the exposed wall elements during the observation period is shown in Fig. 2. Prior to the siloxane impregnation, which was applied in the beginning of June 1993 shortly after the spray wetting of the west facing elements, the moisture change of the west facing elements are very similar. After the impregnation however, the untreated masonry elements are becoming increasingly wet until they reach a dynamic equilibrium, whereas the siloxane impregnated masonry elements dry out continuously. As expected, the drying process is faster in summer than in winter. There appears to be no influence of the cracks on the moisture behaviour of the masonry since the changes in water content with and without cracks between the bricks and the mortar are almost equal for the treated and the untreated wall elements. The effect of the untreated mortar areas in the impregnated facade without cracks introduced in autumn 1995 (hollow circles in Fig. 2 above) seems, however, quite important. The increase in water content compared to the unaltered impregnated masonry element (full circles in Fig. 2) has to be carefully observed in future. The eastward facing sheltered wall elements show no difference in the moisture behaviour for the treated and untreated masonry. The slight increase in material moisture during winter time due to vapour diffusion from the inside and a higher relative humidity on the outside is equal in both cases. That means that the siloxane impregnation has only a minor effect on the vapour diffusion and sorption behaviour of the masonry.

3.2 Comparison of calculation and experiment

The calculated and measured courses of the mean water content of an impregnated and an untreated west facing wall element after the artificial wetting are compared in Fig. 3. The agreement between the calculated results and the measurements is quite good which means that the approximated material parameters are sufficiently accurate in order to obtain realistic calculation results. It also shows that rain water penetration of the impregnated facade is very low because the measured water content hardly deviates from the calculated course where zero water absorption is assumed.

3.3 Calculated moisture behaviour of a representative wall

The annual mean moisture profiles (solid lines) and the annual variation range (hatched areas) in the masonry of a 40 cm thick untreated brick wall with and without interior insulation are shown in Fig. 4. In all cases, the exterior surface shows the highest variation in water content but the annual mean water content there is rather low. The variations are decreasing rapidly towards the interior of the wall, whereas the mean water content increases steeply. While the annual mean moisture reaches a peak of about 8 Vol.-% in the masonry without insulation, the maximum with interior insulation lies above 10 Vol.-%. This means that the frost damage risk of a brick facade is considerably increased by applying an interior insulation. Compared with the uninsulated wall, the influence of the type of insulation on the moisture behaviour of the masonry is not significant. This shows that there is no risk-free interior insulation measure, because the reduction in masonry temperature seems to be more important for the drying process than the vapour permeability of the insulation layer. A low vapour diffusion resistance leads to better drying conditions during summer time which are almost compensated by interstitial condensation during the heating period.

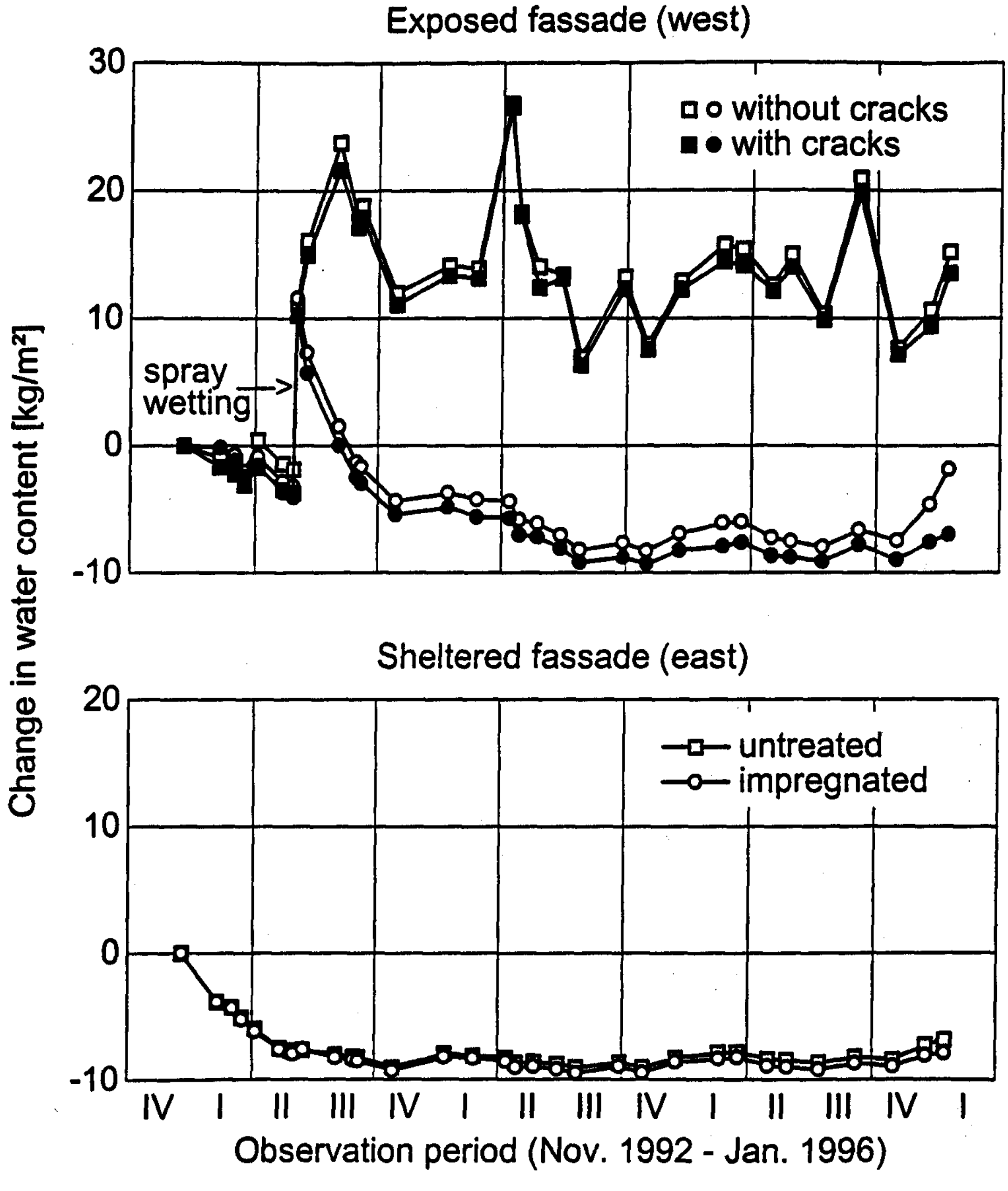

Fig. 2: Moisture behaviour of the exposed masonry elements over a period of approximately three years. The roman numbers indicate the quarters of a year. The impregnation of the exterior surface of the elements was done shortly after the spray wetting.

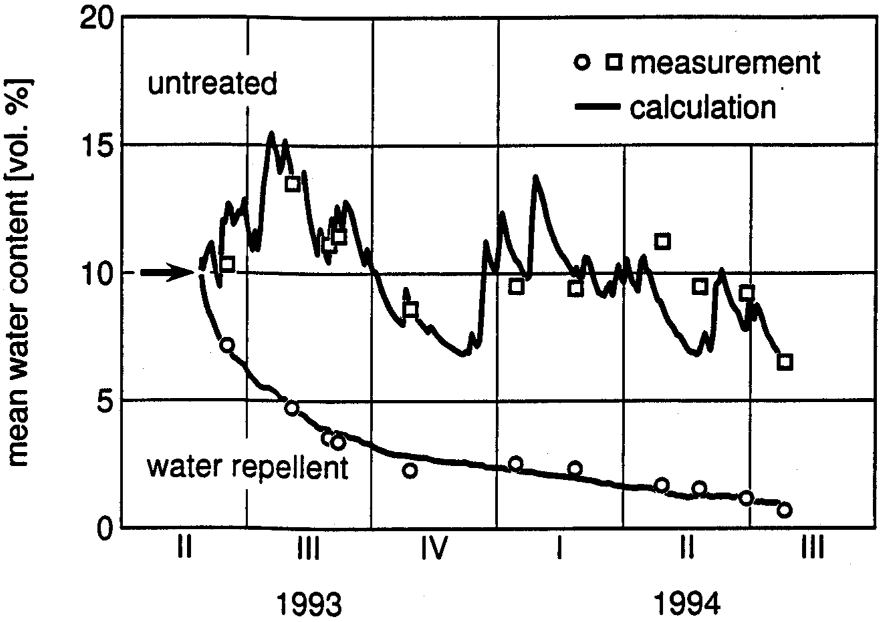

Fig. 3: Comparison of the calculated and the measured variation in water content of 24 cm thick brick masonry under natural conditions. The initial water content (marked with an arrow) was reached by artificial spray wetting of the facade elements.

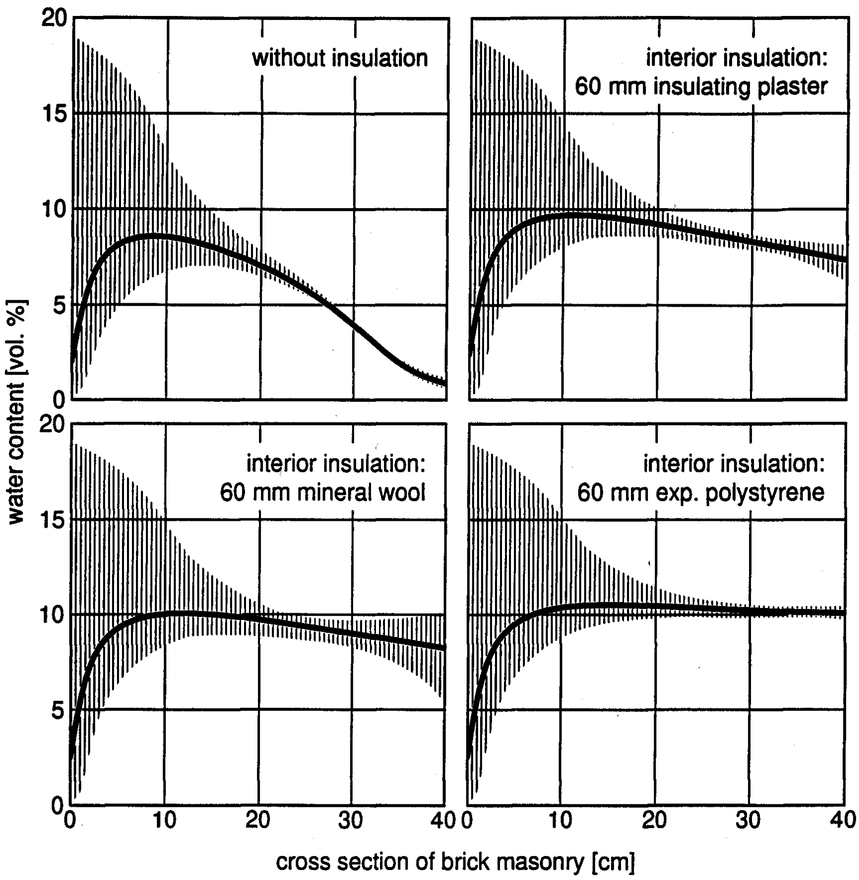

Fig. 4: Annual mean profiles (solid lines) and annual variations (hatched areas) of the water content in the masonry of a west oriented wall without and with different types of interior insulation.

If the moisture content in the masonry shown in Fig. 4 is regarded to be too high, an impregnation of the facade may be considered. However, an immediate change of the moisture conditions after application of the water repellent agent should not be expected. Fig. 5 shows the development of the mean water content in the masonry with and without insulation starting from the calculated moisture profiles analogous to those in Fig. beginning of July after facade impregnation. While the uninsulated masonry reaches the practical moisture content of 1.5 Vol.-% in less than two years, it takes more than five years for the insulated walls to dry out completely.

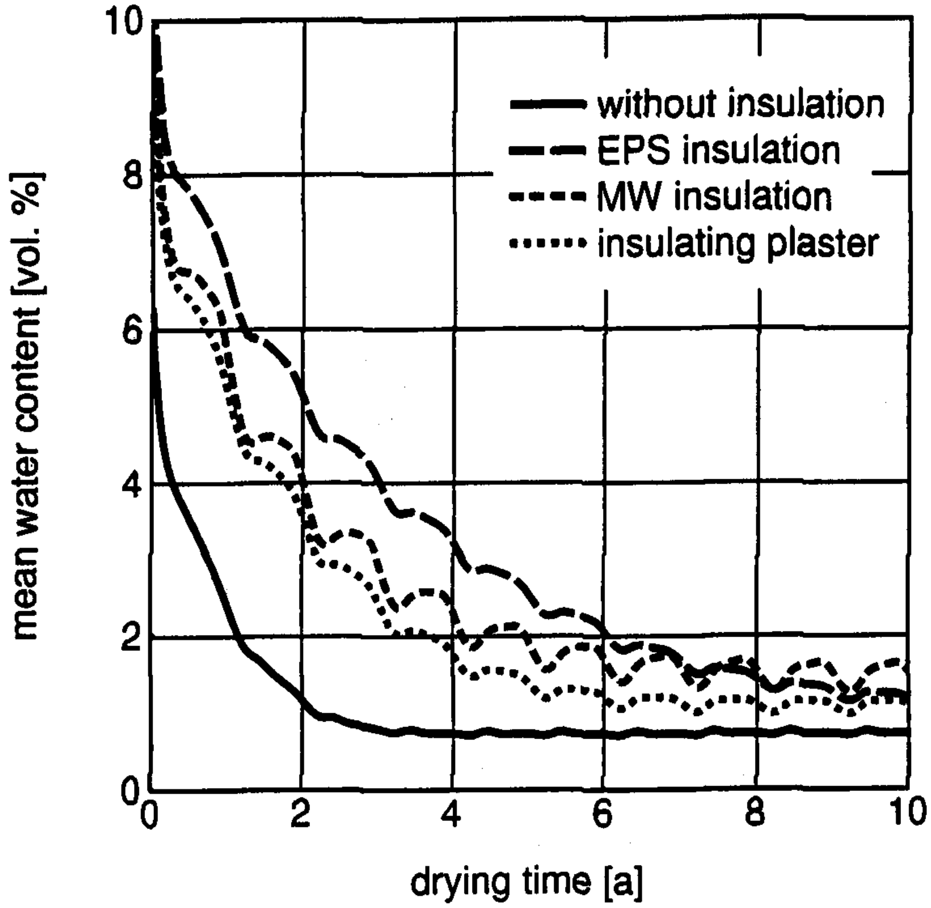

Fig. 5: Drying behaviour of unrendered brick walls without and with different types of interior insulation after impregnation. The initial water content in the walls corresponds to the respective condition at the beginning of July without impregnation.

4. Discussion of the results and conclusion

The field test shows that a siloxane impregnation, if properly applied, can repel rain water to such an extent that a complete drying of the masonry is possible. The question remains, however, whether the experience from rather small test elements even with artificial cracks which were impregnated by experts can be translated into the application on a real building. It seems possible that in inappropriate impregnation can even increase the moisture content and hence the danger of frost damage as stated in [6]. The quality of workmanship and the preparation of the facade, for example by repointing it, appear to be of major importance. If the quality conditions are met, an impregnation can be considered as an effective rain protection. Small cracks up to 1 mm wide do not affect the rain protection if they are thoroughly impregnated and if the wall is of sufficiently low air permeability, e.g. by the application of a plaster on the inside. A similar result for cracks up to 0.5 mm has been obtained by laboratory simulations [7].

The drying time of the masonry even after an effective impregnation should not be underestimated. It is recommendable to install an interior insulation after the impregnation and leaving some time for the excessive moisture in the masonry to dry out. Finally, it should be noted that a high accumulation of salt in the brickwork may impede the drying process or even prevent it altogether [8]. Under these circumstances, impregnation measures may fail to have the desired effect or even worse, salt crystallisation behind the impregnated surface layer may lead to spalling effects at the facade. If the moisture in the wall is not due to ran but to rising damp, an impregnation can result in a further rise of the water front.

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